

Department of Environmental and Forest Biology, State University of New York,  
College of Environmental Sciences and Forestry, Syracuse, New York, U.S.A.

## Effect of sewage sludge on decomposition processes in soils

B. G. STEVENSON, C. M. PARKINSON, and M. J. MITCHELL

With 2 figures

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### 1. Introduction

Several studies have shown that agriculture and silviculture can use sewage sludge as an energy and nutrient subsidy (SOPPER & KARDOS 1973; MANSON & MERRITT 1975; KELLING *et al.* 1976). However, the potential for uptake of heavy metals by food crops and spread of pathogens constrains the use of sludge as an agricultural fertilizer. Forest lands minimize this problem since edible crops are rarely harvested. Potential pollutants are dispersed and diluted throughout the forest ecosystem, although heavy applications of sludge [ $125 \text{ Mg} \triangleq 125 \text{ t wet mass ha}^{-1}$ ]<sup>1</sup>) to hardwood forests can increase the concentration of most ions in soil water (KOTERBA *et al.* 1979). Most forests have various functional forms and species of plants which extend and diversify the periods of nutrient uptake from sludge because of their different ecological requirements.

Decomposition and resultant stabilization of sludge depends upon the activities of forest soil microflora and invertebrates. Nematodes are a dominant component of sludge fauna and enhance sludge decomposition (ABRAMS & MITCHELL 1980a, 1980b; MITCHELL *et al.* 1980a). Earthworms fragment organic matter within forest soils and aid in the incorporation of this material into mineral soil. Addition of sludge, slurries or sewage effluents to soil generally stimulates the growth of endemic earthworm populations (CURRY 1976; DINDAL *et al.* 1979). It has been proposed that certain earthworm species, such as *Eisenia foetida* (SAVIGNY), can help in sludge management. Passage of sludge through the gut of *E. foetida* accelerates sludge decomposition and stabilization (MITCHELL *et al.* 1978, 1980b; MITCHELL 1979).

The present study evaluated the effects of sewage sludge additions to an old field and two forest soils. The objectives of the study were: (1) to determine decomposition rates in soils with and without sludge amendments, (2) to monitor the effects of sludge additions on specific abiotic and biotic parameters (*Eh*, moisture content, and nematode and enchytraeid population densities), and (3) to determine the effects of addition of *E. foetida*.

### 2. Materials and methods

#### 2.1. Description of vegetative sites and experimental plots

In the fall of 1979, four  $2 \times 2 \text{ m}$  experimental plots were established in each of three sites at the Lafayette Experimental Station, Syracuse, New York. The sites were an old field, a mixed hardwood forest, and a Norway spruce [*Picea abies* (L.)] plantation. Dominant vegetation in the old field consisted of grasses (Gramineae) and the soil was an Ontario sandy loam. Sugar maple (*Acer saccharum* MARSH.) and red oak (*Quercus rubra* L.) dominated the hardwood site; the soil was a Cazenovia sandy loam. The soil type of the spruce plantation was an Ontario sandy loam. Experimental plots were edged with wooden boards buried about 15 cm deep.

<sup>1</sup>) 1 Mg (Megagram)  $\triangleq$  1 t (metric ton)  $\triangleq$   $1 \times 10^6 \text{ g}$ .

## 2.2. Sludge application

In October 1979, 400 kg of wet municipal wastewater sludge from the Meadowbrook-Limestone Wastewater Treatment Plant (Manlius, Onondaga Co., New York) were applied to each of two plots at each site to a depth of 5 cm. Earthworms (*E. foetida*) also were added to two plots at each site (1,500 to 1,600 ind. m<sup>-2</sup>), including one sludge-treated plot. Thus, within each site, four treatment plots were established: a control plot (C), a worm-treated plot (W), a sludge-treated plot (S), and a sludge- and worm-treated plot (SW).

## 2.3. Gas flux measurements

Oxygen consumption and carbon dioxide evolution were analyzed only in the old field and hardwood forest due to time and equipment limitations. Three glass cylinders (30 cm height, 10 cm diameter) were installed (10 cm deep) in each treatment plot before sludge application or worm addition. Sludge and *E. foetida* worms were added within the cylinders. To determine changes in gas concentrations, each cylinder was sealed for 2 h and covered with black plastic to prevent photosynthesis. A gas sample was taken with an evacuated 100 ml flask within the cylinder. Gas concentrations were analyzed by gas chromatography and gas fluxes were determined using methods described elsewhere (ABRAMS & MITCHELL 1978; MITCHELL *et al.* 1978).

## 2.4. Population densities of nematodes and enchytraeids

Three cores (5.5 cm diameter) were removed from each plot outside of the glass cylinders and each core was divided into two depths (0–3 cm and 3–6 cm). Nematodes and enchytraeids were extracted in Baermann funnels from subsamples of each depth (BROWN *et al.* 1978; MITCHELL *et al.* 1978).

## 2.5. *Eh*, moisture content, and temperature

Replicate layers from the 0–3 cm and 3–6 cm depths were mixed following removal of samples for invertebrate extraction. *Eh* was determined from a combined sample at both depths using a platinum electrode (MITCHELL *et al.* 1978, 1980b). Moisture content was determined by drying the samples used for invertebrate extraction to a constant mass at 105 °C. Temperature was read from thermocouples placed in the 0–3 cm and 3–6 cm depths.

## 2.6. Sample schedule

Data were collected from 6 October to 12 December 1979 and from 31 March to 19 June 1980. During the fall, moisture content, *Eh*, temperature, and densities of nematodes and enchytraeids were determined once a week through day 35 when biological activity was greatest, and once every two weeks thereafter. Gas collections were made every five days through day 40 and once after approximately 25 days. During the spring, data on all parameters were collected once every two weeks.

# 3. Results and discussion

## 3.0. General

Results were calculated by analysis of variance (ANOVA) in which site (old field, hardwood forest, and spruce plantation), sludge (present or absent), *E. foetida* (present or absent), and depth (0–3 cm or 3–6 cm) were main treatments. Time in days and soil temperature were covariates. Data collected in fall 1979 and spring 1980 were analyzed separately.

## 3.1. Effects of *Eisenia foetida* addition

Addition of *E. foetida* had no effect on *Eh* (fall only), moisture content, or nematode and enchytraeid population densities (ANOVA: all  $p > .05$ ). The results for invertebrate densities differ from previous studies in which feeding upon sludge by *E. foetida* or an isopod, *Oniscus asellus* L., increased population densities of bacteriophagous nematodes (BROWN *et al.* 1978; MITCHELL *et al.* 1980a, 1980b). In the present study, *E. foetida* probably dispersed rapidly out of the treatment plots soon after inoculation and thus had limited effects on biological or physical properties of sludge or soil. *E. foetida* evades unfavorable environmental conditions by dispersal (GRANT 1955).

Gas fluxes were greater in worm-treated plots than in untreated ones during fall (ANOVA: both  $O_2$  and  $CO_2$ ,  $p < .01$ ). Unlike the rest of the plot, worms could not escape from the glass cylinders used for gas flux measurements. Thus, containment of *E. foetida* produced localized and relatively intense burrowing and egestion, which resulted in stimulation of microbial respiration (MITCHELL *et al.* 1978, 1980b; HORNER & MITCHELL 1981). The absence of a worm effect on gas flux rates in spring (ANOVA: both  $O_2$  and  $CO_2$ ,  $p > .05$ ) was probably due to winter mortality of the worms, since winter temperatures fell below the lower tolerance limit of *E. foetida* (NEUHAUSER *et al.* 1980; KAPLAN *et al.* 1980).

Greater *Eh* occurred in the W and SW plots during spring only (ANOVA:  $p < .01$ ). This result is an artifact due to plot variability associated with higher moisture levels in some plots.

### 3.2. Effects of sludge addition

#### 3.2.1. Redox potential (*Eh*)

Sludge addition resulted in lower *Eh* for all three sites in both fall and spring (ANOVA all  $p < .01$ ; Table 1). When sludge was added to soil, it served as a rich source of electron donors which depleted oxygen and alternate electron acceptors. Thus, it depressed the redox potential. TAYLOR *et al.* (1978) found that soil amended with raw sludge produced more methane than soil amended with digested sludge since the latter sludge had fewer electron donors. A general consequence of depressed *Eh* and anaerobic conditions is the reduction of decomposition due to the lower metabolic efficiency of anaerobiosis.

Sludge in drying beds may be subject to a low *Eh* and anaerobic condition (MITCHELL *et al.* 1980b). In contrast to drying beds, addition of sludge to soil elevates *Eh* in sludge due to the loss of sludge moisture and increased oxygen availability. All mean values for *Eh* in C plots were within the range for oxidized soil (+400 mV to +700 mV) (PATRICK & DELAUNE 1977) while *Eh* in S and SW plots was moderately reduced in fall and became oxidized by spring (Table 1).

#### 3.2.2. Moisture content

In all three sites, greater moisture content resulted from sludge addition to soil in both fall and spring (ANOVA: both  $p < .01$ ; Table 1). Sludge additions to soil increase the moisture content of surface soil (MITCHELL *et al.* 1978) which results in decreased oxygen availability (MITCHELL & HORNER 1980). With increased drying, oxygen availability increases, but there is a simultaneous decrease in decomposition activity (HORNER & MITCHELL 1981).

Differences in soil moisture content occurred among the sites in both seasons (ANOVA: both  $p < .01$ ; Table 1). A gradient of cover existed on the sites: the old field was open and unshaded, the spruce plantation was closed and shaded, and the hardwood forest was intermediate (shaded only part of the year). Sludge on the old field dried rapidly and its volume decreased. Sludge on the spruce plantation remained wet throughout the study and maintained a depth of approximately 5 cm. The hardwood forest showed an intermediate condition. These site differences have important implications for land management of sewage sludge since decomposition and stabilization will proceed slowly and incompletely if moisture conditions are not optimal.

#### 3.2.3. Nematode and enchytraeid population densities

Densities of nematodes were greater in sludge-treated plots than in untreated ones in fall and spring (ANOVA: all  $p < .01$ ), while enchytraeid population densities exhibited differences only in spring (ANOVA:  $p < .01$ ; Table 1). Higher nematode population densities in S and SW plots are attributable to large bacterial populations within sludge (MITCHELL *et al.* 1978, 1980b). MITCHELL *et al.* (1978) showed that sludge addition to topsoil caused

Table 1. Means sites (+ S.E.) of six variables measured from experimental plots established on three vegetative sites

Season	Variable	Sludge	Site		
			Old field	Hardwood forest	Spruce plantation
Fall (10/6/79 to 12/12/79)	Eh	—	460.68 ± 14.75 (84) <sup>1)</sup>	507.43 ± 6.51 (84)	510.75 ± 7.56 (36)
	(mV)	+	348.79 ± 21.64 (84)	290.63 ± 20.19 (81)	315.67 ± 28.89 (36)
	Moisture	—	25.13 ± 0.53 (92)	31.26 ± 2.07 (89)	36.16 ± 2.64 (59)
	(% dr. m) <sup>3)</sup>	+	155.61 ± 14.38 (92)	212.26 ± 13.24 (92)	224.15 ± 17.87 (58)
	Nematodes	—	4.45 ± 0.44 (92)	5.64 ± 1.33 (89)	6.45 ± 0.80 (59)
	(No./g)	+	22.42 ± 4.22 (92)	27.01 ± 3.17 (92)	43.68 ± 6.40 (58)
	Enchytreids	—	0.39 ± 0.06 (92)	0.23 ± 0.13 (89)	0.46 ± 0.13 (59)
	(No./g)	+	0.30 ± 0.12 (92)	0.32 ± 0.13 (92)	0.32 ± 0.16 (58)
	O <sub>2</sub>	—	0.011 ± 0.001 (120)	0.009 ± 0.002 (124)	N.D. <sup>2)</sup>
	(ml O <sub>2</sub> /cm <sup>2</sup> /h)	+	0.031 ± 0.002 (126)	0.037 ± 0.003 (136)	N.D.
Spring (3/31/80 to 6/19/80)	CO <sub>2</sub>	—	0.021 ± 0.001 (120)	0.01 ± 0.001 (124)	N.D.
	(ml CO <sub>2</sub> /cm <sup>2</sup> /h)	+	0.038 ± 0.002 (126)	0.024 ± 0.002 (136)	N.D.
	Eh	—	531.60 ± 5.54 (60)	544.63 ± 5.44 (48)	544.38 ± 8.96 (24)
	(mV)	+	479.15 ± 6.24 (60)	463.25 ± 7.98 (48)	474.92 ± 6.55 (36)
	Moisture	—	123.69 ± 0.60 (72)	134.47 ± 0.80 (72)	146.29 ± 3.42 (60)
	(% dr. m)	+	164.69 ± 7.35 (72)	184.05 ± 6.28 (72)	217.56 ± 6.43 (60)
	Nematodes	—	3.02 ± 0.35 (72)	2.55 ± 0.28 (71)	5.51 ± 0.79 (58)
	(No./g)	+	22.17 ± 3.22 (72)	34.34 ± 4.95 (71)	41.75 ± 6.09 (60)
	Enchytraeids	—	0.17 ± 0.04 (72)	0.18 ± 0.05 (71)	0.62 ± 0.13 (58)
	(No./g)	+	0.67 ± 0.17 (71)	1.02 ± 0.30 (71)	1.03 ± 0.22 (60)
	O <sub>2</sub>	—	0.024 ± 0.001 (66)	0.012 ± 0.001 (72)	N.D.
	(ml O <sub>2</sub> /cm <sup>2</sup> /h)	+	0.050 ± 0.003 (68)	0.030 ± 0.002 (70)	N.D.
	CO <sub>2</sub>	—	0.021 ± 0.001 (66)	0.011 ± 0.001 (72)	N.D.
	(ml CO <sub>2</sub> /cm <sup>2</sup> /h)	+	0.038 ± 0.002 (68)	0.024 ± 0.002 (70)	N.D.

<sup>1)</sup> Numbers in parentheses are sample sizes.<sup>2)</sup> N.D. = not determined.<sup>3)</sup> dr.m. = dry mass.

Note: Means are given for plots with sludge (+) and without sludge (—).

rapid increases in densities of bacteriophagous nematodes. Nematodes, in turn, stimulate bacterial growth and metabolism (ABRAMS & MITCHELL 1980b). The sludge effect on these worms also accounts for the fact that population densities of nematodes were highest in the 0–3 cm depth in both seasons, as was enchytraeid density in spring (ANOVA: all  $p < .05$ ).

The absence of a sludge effect on enchytraeid population density in fall was probably attributable to a lack of recruitment during this period. Population growth of enchytraeids may have been retarded further because of dry soil conditions in fall.

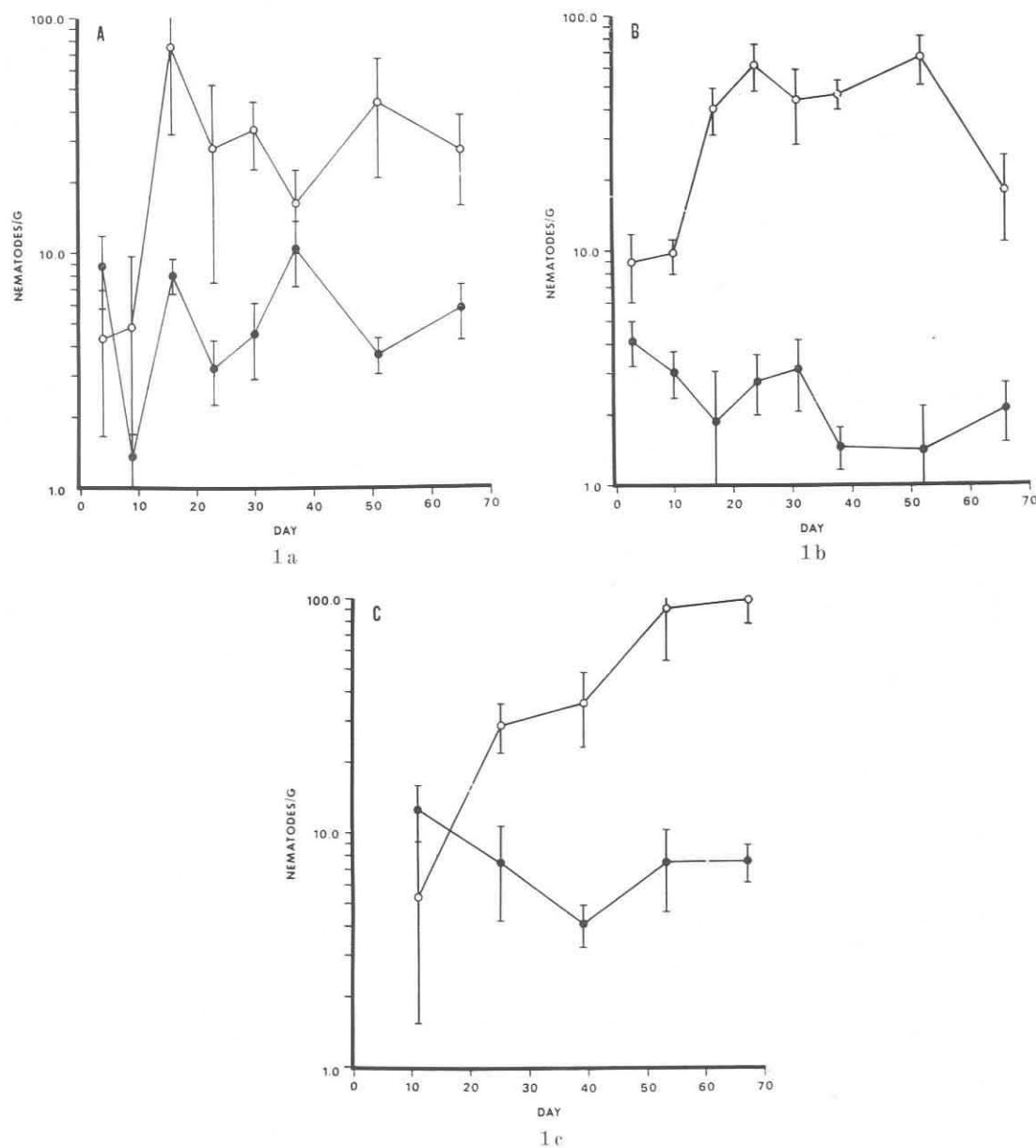


Fig. 1. Changes in nematode population densities over time in the three vegetative sites. Densities are from the 0–3 cm depth. (Solid circles = untreated plots, open circles = sludge-treated plots. A = old field, B = hardwood forest, C = spruce plantation.)

Differences in nematode densities occurred between sites in both fall and spring (ANOVA: both  $p < .01$ ). Site differences in nematode populations paralleled variation in moisture content (Table 1).

Nematodes in sludge (0–3 cm depth) increased rapidly on the old field and hardwood forest sites for about 3 weeks (Fig. 1). Nematode densities in sludge on the spruce plantation increased during the entire fall. Similar rapid increases in nematode populations were found in sludge-amended soil in a glasshouse experiment (MITCHELL *et al.* 1978) and in laboratory microcosms (ABRAMS & MITCHELL 1980b).

To estimate maximum doubling times of nematode populations in the sludge-amended soils, population densities on days 16, 24, and 67 (fall data) were used as maxima for populations in the old field, hardwood, and spruce sites, respectively. Doubling times were calculated assuming logarithmic growth (Table 2). Doubling times were inversely related to mean soil temperature. Nematode densities increased most rapidly on the site with the highest soil temperature (old field). Doubling times at a given temperature were less than those found in previous studies of nematodes in sludge and soil (Table 2).

Table 2. Doubling times of nematode populations (in days) under various environmental conditions

Study conditions	Temperature (°C)	Nematode taxa	Doubling time (d)	Reference
Laboratory microcosms of sludge	5	<i>Pelodera punctata</i> (COBB) (Rhabditidae)	24	ABRAMS & MITCHELL 1980
	15		5.0	
	22		2.2	
Laboratory microcosms of sludge	22	All, primarily Rhabditidae	14	MITCHELL <i>et al.</i> 1980a
Soil	20	Rhabditidae	3 to 4	SCHIEMER 1975
Sludge-amended soil in a glasshouse	23	All, primarily Rhabditidae	2.78	MITCHELL <i>et al.</i> 1978
Sludge-amended soils		All, primarily Rhabditidae		Present study
Old field	13		2.80	
Hardwood forest	8		6.73	
Spruce plantation	6		13.9	

### 3.2.4. Decomposition rates

Carbon dioxide evolution is the most common method of measuring decomposition rates, although results often are confounded by the high solubility of CO<sub>2</sub> in some soils. Thus, oxygen consumption usually is a more reliable index of respiration and therefore of decomposition. Rates of flux for both gases were greater in the sludge-treated plots than in the untreated ones in both seasons (ANOVA: all  $p < .01$ ; Table 1). Previous studies have demonstrated that addition of sludge to soil increases respiration due to the utilization of labile carbon compounds (HARTENSTEIN 1981; HSIEH *et al.* 1981). Rapid mineralization of labile carbon followed by slow decomposition of recalcitrant portions produces an exponential decline in the decomposition rate under constant temperatures (GILMOUR & GILMOUR 1980; HSIEH *et al.* 1981; TERRY *et al.* 1979a, 1979b). Fig. 2 shows that sludge-treated plots exhibited similar declines although variable soil temperatures produced variation in decomposition rates.

The rate of change in decomposition rates was approximately an order of magnitude greater in sludge-treated plots than in untreated ones during fall (Table 3). By spring, this rate of change in S and SW plots was only 5 times as great as the rate in C and W plots. (The regression coefficients were negative for fall data since gas flux rates declined with

decreasing soil temperatures. Positive coefficients occurred in spring since the rates increased with warming soil.) Thus, decomposition rates declined more rapidly in sludge-treated plots than in untreated ones in fall, and increased more rapidly during spring. These differences are attributable to greater amounts of labile carbon in sludge which permitted high decomposition rates during warm weather.

Decomposition rates from this study were compared with rates derived from other forest and field sites and from other sludge-amended soils. To make these comparisons, rates of CO<sub>2</sub> production from both this study and the literature were converted to gC out-

Table 3. Rates of change in decomposition with vegetative site and with addition of sludge

Season	Site	Sludge	O <sub>2</sub>	CO <sub>2</sub>
Fall	Old	—	$-0.78 \pm 0.65$ (120)	$-0.60 \pm 0.35$ (120)
	Field	+	$-6.57 \pm 1.10$ (126)	$-5.22 \pm 0.68$ (126)
	Hardwood	—	$-6.20 \pm 0.93$ (124)	$-0.73 \pm 0.14$ (124)
	Forest	+	$-9.06 \pm 1.41$ (136)	$-4.04 \pm 0.72$ (136)
Spring	Old	—	$+2.20 \pm 0.47$ (66)	$+1.66 \pm 0.39$ (66)
	Field	+	$+5.76 \pm 0.84$ (68)	$+4.89 \pm 0.65$ (68)
	Hardwood	—	$+1.28 \pm 0.26$ (72)	$+1.10 \pm 0.16$ (72)
	Forest	+	$+5.19 \pm 0.49$ (70)	$+4.66 \pm 0.42$ (70)

Note: absent (—), present (+). Reported values are coefficients of regression [ $\pm$  S.E. (number of samples)] for gas fluxes ( $\text{ml} \cdot \text{m}^{-2} \cdot \text{h}^{-1} \cdot \text{d}^{-1}$ ).

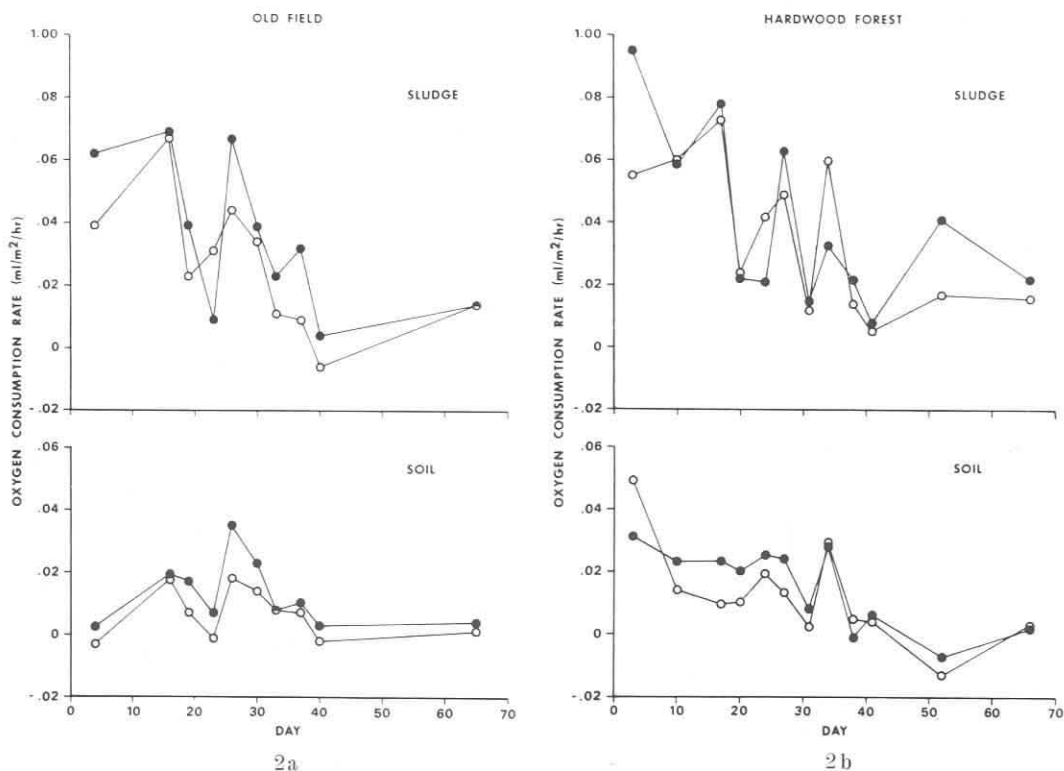


Fig. 2. Oxygen (O<sub>2</sub>) consumption rate ( $\text{ml O}_2 \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ ) over time in samples [with (●) and without (○) *Eisenia foetida*] from the old field and hardwood forest sites.

Table 4. Decomposition rates under various environmental conditions, including addition of sewage sludge to soil

Habitat	Site conditions	Decomposition rate ( $\text{gC} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ )	Reference
Sites without sludge amendments			
Temperate forest	Evergreen forest	2.89	KIRITA 1971
	Evergreen oak forest	3.87	KIRITA 1971
	<i>Liriodendron</i> forest (40—50 yrs old)	2.93	EDWARDS 1975; EDWARDS & SOLLINS 1973
	Evergreen oak forest	3.01	NAKANE 1975
	<i>Pinus</i> forest ( $\sim 15$ yrs old)	1.64	INO & MONSI 1969
	Mean for 3 forests ( <i>Quercus</i> , <i>Acer</i> and <i>Pinus</i> )	1.13	WITKAMP 1966
	<i>Pinus</i> forest ( $\sim 40$ yrs old)	0.83	WITKAMP & FRANK 1969
	<i>Quercus-carya</i> forest (50 yrs old)	2.77	GARRETT & COX 1973
	Montane <i>Fagus</i> and <i>Fagus-Abies</i> forests (60—90 yrs old)	1.17	VIRZO DE SANTO <i>et al.</i> 1976
	<i>Quercus</i> forest and fen forest	2.06	REINERS 1968
	Mixed <i>Quercus-Fagus</i> forest	0.48	FROMENT 1972
	<i>Fagus</i> forest (150 yrs old)	0.47	PHILLIPSON <i>et al.</i> 1975
	Mean of <i>Castanea</i> and <i>Fagus</i> forests (40—60 yrs old)	1.52	ANDERSON 1973
	<i>Quercus-Fagus</i> forest (135 yrs old)	0.61	DEBOOIS 1974
	Mixed <i>Quercus-Acer</i> forest		Present study
	Fall-with <i>E. foetida</i>	1.10	
	Spring-with <i>E. foetida</i>	1.49	
	Fall-without <i>E. foetida</i>	1.02	
	Spring-without <i>E. foetida</i>	1.45	
	Field	0.98 to 1.15	COLEMAN 1973
	Laboratory	0.20	INO & MONSI 1969
	Field	1.23	KUCERA & KIRKHAM 1971
	Field	0.45	WILDUNG <i>et al.</i> 1975
Temperate grassland	Specieal diffusion theory calculations	0.41 to 1.22	DEJONG & SHAPPERT 1972; DEJONG <i>et al.</i> 1974
	Old field		Present study
	Fall-with <i>E. foetida</i>	1.34	
	Spring-with <i>E. foetida</i>	2.92	
	Fall-without <i>E. foetida</i>	1.18	
	Spring-without <i>E. foetida</i>	2.27	
Sites with sludge amendments			
Man-made	Sludge drying beds	8.82	MITCHELL <i>et al.</i> 1980b
Temperate forest	Laboratory microcosms	1.46 to 4.23	MITCHELL <i>et al.</i> unpubl. data
	Mixed <i>Quercus-Acer</i> forest		Present study
	Fall-with <i>E. foetida</i>	3.21	
	Spring-with <i>E. foetida</i>	3.33	
	Fall-without <i>E. foetida</i>	2.84	
	Spring-without <i>E. foetida</i>	2.70	
Temperate grasland	Laboratory microcosms	1.56 to 9.33	MILLER 1974
	Laboratory microcosms	2.00 to 3.90	TERRY <i>et al.</i> 1979a
	Old field		Present study
	Fall-with <i>E. foetida</i>	3.14	
	Spring-with <i>E. foetida</i>	4.84	
	Fall-without <i>E. foetida</i>	2.57	
	Spring-without <i>E. foetida</i>	4.75	



put  $\cdot \text{m}^{-2} \cdot \text{d}^{-1}$ . The following assumptions and simplifications were made: (1) seasonal and daily variation in carbon output of soil or sludge was ignored (except for the present values), (2) a liter of  $\text{CO}_2 = 0.54 \text{ g of C}$  (SCHLESINGER 1977), (3) the R.Q. for soil respiration was 0.82 (MITCHELL 1979), and (4) the specific density of sludge  $\triangleq 1 \text{ g cm}^{-3}$ .

Rates of carbon output for the plots without sludge are in close agreement with decomposition rates reported from similar communities (Table 4). The range of reported values for temperate forests is  $0.47$  to  $3.87 \text{ gC} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ , which includes all values measured in the forest plots without sludge. The reported range for temperate grasslands is  $0.20$  to  $1.23 \text{ gC} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ , which includes the fall measurements from the old field plots without sludge. Spring values exceeded the reported maximum rates of decomposition (Table 4). Root respiration, which was included in the gas flux measurements, may have been higher than in the other studies since this site was a monoculture grass field undergoing rapid growth.

Sludge-treated plots exhibit decomposition rates which are similar to rates from other sludge-amended soils but which are less than the value from sludge drying beds (Table 4). In all cases, addition of sludge to soil increases carbon output over untreated soils. This increase is attributable to decomposition of the large amount of organic carbon in sludge.

#### 4. Conclusions

In general, the results of this study are in accord with previous studies on application of sewage sludge to soil. Sludge decomposition decreases with time but the rate of decrease is affected by temperature, moisture and other factors. Macroinvertebrates accelerate decomposition rates by increasing microbial densities and respiration rates. In this study, the effect of *E. foetida* was localized within gas measurement cylinders; dispersal of remaining worms out of the experimental plots limited their effects on sludge decomposition within the plots. Finally, nematode densities are higher in sludge-amended soils than in untreated ones. These organisms also accelerate decomposition by stimulation of bacterial metabolism and prevention of bacteriostasis.

Application of sewage sludge to forested lands is a realistic and environmentally sound alternative to incineration and other methods of sludge disposal. Soil microbiota and other invertebrates are capable of decomposing this material and incorporating it into mineral soil. However, *E. foetida* may not be an effective organism for stabilization of land-applied sludge *in situ* since it disperses from inhospitable conditions.

#### 5. Acknowledgements

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Address of the authors: [Dr. BRUCE G. STEVENSON (corresponding author)]. Department of Environmental and Forest Biology, State University of New York, College of Environmental Science and Forestry, Syracuse, New York 13210, U.S.A.

#### Synopsis: *Original scientific paper*

STEVENSON, B. G., C. M. PARKINSON & M. J. MITCHELL, 1984. Effect of sewage sludge on decomposition processes in soils. *Pedobiologia* **26**, 95—105.

The effects of sludge amendment and addition of the earthworm, *Eisenia foetida*, to an old field soil and two forest soils was studied in central New York. Experimental plots were established in the old field, a mixed hardwood forest, and a spruce plantation. In each site, municipal wastewater sludge was added to two plots and *E. foetida* were placed in two plots, including one sludge-treated plot. Redox potential (*Eh*), moisture content, nematode and enchytraeid densities, and fluxes of oxygen and carbon dioxide were monitored in the plots.

Addition of *E. foetida* produced limited effects on *Eh*, moisture content, and densities of invertebrates since these earthworms dispersed after inoculation. Worms which were added to glass cylinders used for gas flux measurements could not disperse. Containment of *E. foetida* produced localized and relatively intense burrowing and egestion, which resulted in stimulation of microbial respiration and increased fluxes of O<sub>2</sub> and CO<sub>2</sub>.

Sludge addition to soil caused reduced *Eh*, and increased moisture content, invertebrate densities, and rates of decomposition. Sludge had very high moisture content when it was applied, which accounted for increased moisture content and caused reduced *Eh* on sludge-treated plots. Large amounts of labile sludge carbon permitted rapid microbial growth and metabolism, which produced increased gas fluxes. Decomposition rates in sludge-treated plots were comparable to previous studies of sludge-amended soils. Higher densities of bacteriophagous nematodes in sludge were attributable to the large bacterial populations.

**Key words:** Decomposition, Lumbricidae, *Eisenia foetida*, Enchytraeidae, Nematod, forest, old field, sewage, sludge.